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Comparison of the resistance to cavitation and abrasive wear of deposited layers prepared from steels 06X19H9T and Fe-Cr-Ti-Al

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Abstract. The resistance of deposited layers to cavitation erosion and abrasive wear was evaluated for the steels AISI 321 (known as 06X19H9T manufactured according to the Russian standard GOST 18143-72) and Fe-Cr-Ti-Al (two materials namely Ural AS-3 and PPM-6). The Gas Tungsten Arc Welding (GTAW or TIG) process was utilized to deposit these welding material wires onto a medium carbon steel substrate AISI 1040. Cavitation test was conducted by using ultrasonic vibratory method to induce the erosion. In addition, a three-body abrasion test was used to evaluate the resistance of the studied materials to abrasive wear. The material loss criterion and wear rate of each material as a function to testing time were evaluated and discussed. The cavitation and abrasive wear tests have shown similar results regarding the PPM-6 steel. Among the tested material, PPM-6 exhibited the better resistance to cavitation and abrasion. The 06X19H9T stainless steel exhibited a higher resistance to cavitation comparing with the Ural AS-3. With respect to the abrasive wear, Ural AS-3 was to some degree better than the 06X19H9T in resistance to abrasion.

1. Introduction

Wear, in general, is common to occur in machinery components that serve many industrial applications in the fields of oil, mining and mineral processing. Abrasive wear is one of the most important types of wear in which the damage involves a progressive loss of material due to the presence of hard particles rolling between two sliding surfaces. Abrasion wear resistance is very important, therefore; the development of materials and technologies to protect the surfaces of components and increase the wear resistance are necessary for the performance and lifetime of machinery components [1-6]. Hardness affects the abrasive wear resistance of metals such that higher hardness imparts a higher wear resistance, and it can be used as a useful indicator to measure the wear resistance [3, 4]. Many laboratory testing methods can be considered to evaluate the wear resistance. The three-body abrasion test is the most common. The rotating rubber wheel, test specimen, and the solid hard particles are the basic elements in the test which is considered as a low-stress method [7].

Beside the abrasive wear, a recurrent problem which is the wear caused by cavitation occurs frequently in vital components such as pump impellers, turbine blades, valves and marine propellers

[8-10]. Cavitation wear affects certainly the performance and service life of these component. Avoiding or reducing the cavitation effect is necessary from the economic point of view, since cavitation phenomenon would increase maintenance operations and the repairing costs of components [11]. It is defined as formation and collapsing bubbles produced as a result of relative motion between the solid component and a liquid. Collapsing of bubbles near the solid surface is usually accompanied by generating a pulse stress and high velocity micro-jets of liquid, causing fatigue failure and material loss eventually [12]. In this study, the cavitation test condition applied is a combination of mechanical and electrochemical action, since a certain voltage is used along with water as a test liquid. Applying the voltage is to form this interaction of mechanical and electrochemical effect as well as accelerate forming the cavities [13]. The purpose of the current study is to conduct a rubber wheel abrasion test and an ultrasonic vibratory cavitation test for evaluating the resistance of 06X19H9T and Fe-Cr-Ti-Al steels.

2. Experimental procedure

2.1 Deposited Materials. Two types of material systems Fe-Cr-Ti-Al (from now on Ural AS-3 and PPM-6) as well as the austenitic stainless steel 06X19H9T were deposited onto a medium carbon steel substrate AISI 1040. The Gas Tungsten Arc Welding process (GTAW or TIG) was utilized to deposit all the welding wire materials. The 06X19H9T is as a solid wire, while both Ural AS-3 and PPM-6 are in form of cored wire. The chemical compositions of the deposited-welded materials are given in Table 1. The final thickness of the deposited layer was approximately 4-5 mm.

Table 1. The chemical compositions of deposited welding wire materials [wt. %].

Material	C	Cr	Ni	Si	Mn	Al	P	S	Ti	Fe
06X19H9T	Max. 0.08	18.0-20.0	8.0-10.0	0.40-1.00	1.00-2.00	-	Max. 0.03	Max. 0.015	Min. 5×C	Bal.
Ural AS-3	0.83	25.0	0.12	0.5	0.4	1.15	-	-	2.4	Bal.
PPM-6	0.6	8.0	-	-	-	1.5	-	-	1.0	Bal.

2.2 Abrasive wear test. The experiments of the three-body abrasive wear test were carried out on a rubber wheel abrasion test shown in Fig.1. The abrasive particles flow from the container to roll between the test specimen and the rotating rubber wheel. The rubber wheel rotates in the same direction of abrasive particles flow. Abrasive particles used was aluminium oxide of size 125-180 µm. A specific load is placed on the lever arm to form a compressive force towards the rubber wheel and to keep a face contact between the specimen and rubber wheel. The size of test specimen is 70 × 18 × 8 mm^3. The conditions, under which the abrasive wear tests were performed, can be summarized in Table 2.

Table 2. Parameters of the three-body abrasion test

Parameter	value
Load [Kg]	5.0
Rubber wheel rotating speed [rev/min]	75
Rubber wheel diameter [cm]	20
Flow rate of grits [g/min]	110
Total testing time [min]	10
Testing time interval [min]	1.0
Weight distance [cm]	30

The measurements of material weight loss were taken every minute using an analytical weight device with an error 1.0 mg.

2.3 Cavitation test. The test specimens were prepared according to the requirements of ASTM standard G32–10 [14]. The cavitation test conditions applied in this study to conduct the experiments of ultrasonic vibratory tests are shown in Table 3. Water was used as a test solution and a certain voltage (12 V) has been applied with water to accelerate the cavitation and give a combined mechanical-electrochemical effect. The description of working principle of the cavitation test developed by authors [15] is used in this study, as shown in Fig. 2. The total exposure time of cavitation test was 330 minutes. The weight device with an error of 0.5 mg was used to evaluate the weight loss of test specimens.

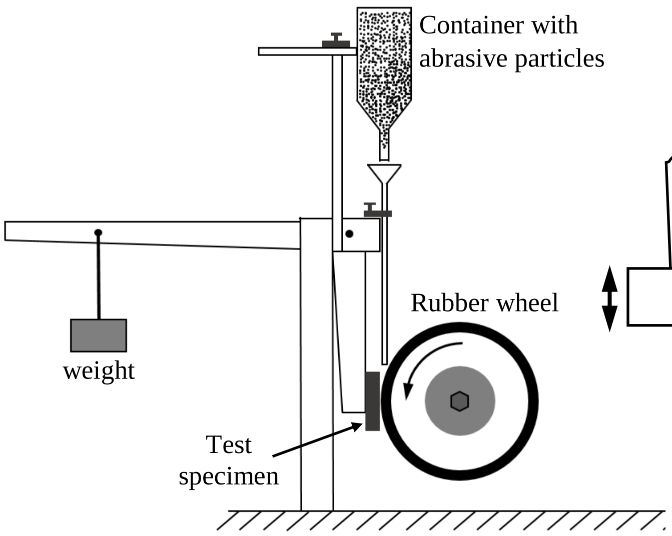

Figure 1. Schematic diagram of Brinell-Hovart rubber wheel abrasion wear test.

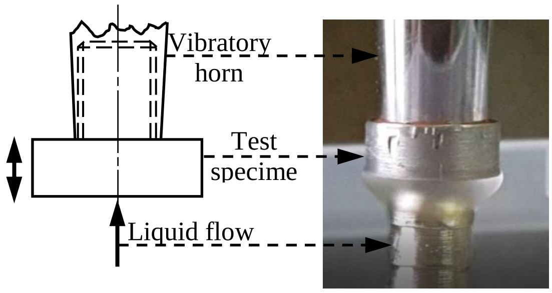

Figure 2. The work principle of the cavitation test.

Table 3. Cavitation test conditions.

Frequency of vibration	20±0.1 [kHz]
Peak-to-peak of amplitude displacement	55±3 [µm]
Power of the ultrasonic generator	500 [W]
Cavitation medium	water
Applied voltage	12 [V]
Total testing time	330 [min]

3. Results and Discussion

3.1 Abrasive wear results. The results of the abrasion test represented by mass loss and wear rate as a function of testing time for all deposited materials and substrate are shown in Figs. 3 and 4, respectively. The difference in mass loss between the deposited materials and substrate can be easily compared. There is a slight difference in mass loss between Ural AS-3 and the 06X19H9T so that Ural AS-3 is better than the 06X19H9T by 10% approximately. The best material among all the studied materials was PPM-6. It exhibited a higher resistance to the abrasive wear comparing with the Ural AS-3 and 06X19H9T by approximately 41% and 56%, respectively. With respect to the speed of mass loss, Fig. 4 represents the abrasive wear rate as a function of testing time for all tested materials. A little difference can be recognized between Ural AS-3 and 06X19H9T particularly at the beginning of test, while a distinct difference can be seen comparing with the PPM-6. To compare the wear rate at each interval of testing time, Fig. 5 shows the abrasive wear rates of all tested materials during the test.

The maximum abrasive wear rate had been recorded for the substrate material AISI 1040, which was of 90 mg/min, while the minimum abrasive wear rate was of 31 mg/min for PPM-6 material. The abrasive wear rate is calculated using Eq. 1.

$$\text{Wear rate} = \frac{\Delta w}{\Delta t} \tag{1}$$

where: Δw is the difference in mass of test specimen between two sequential periods in mg, and Δt is the difference in testing time between these two periods in minutes.

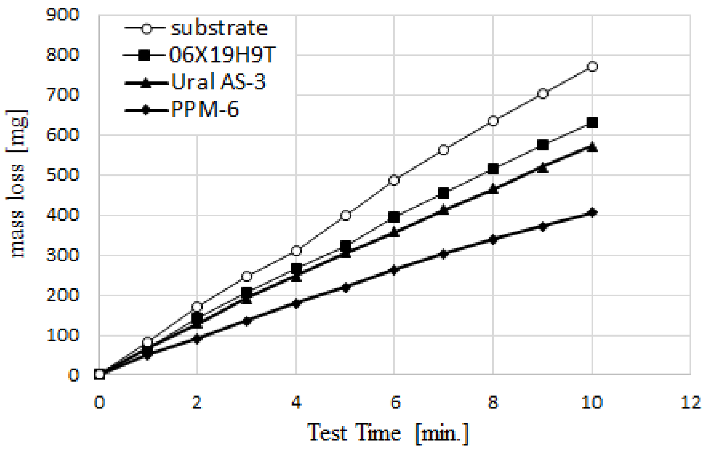

Figure 3. Results of three-body abrasion test of all studied materials (mass loss).

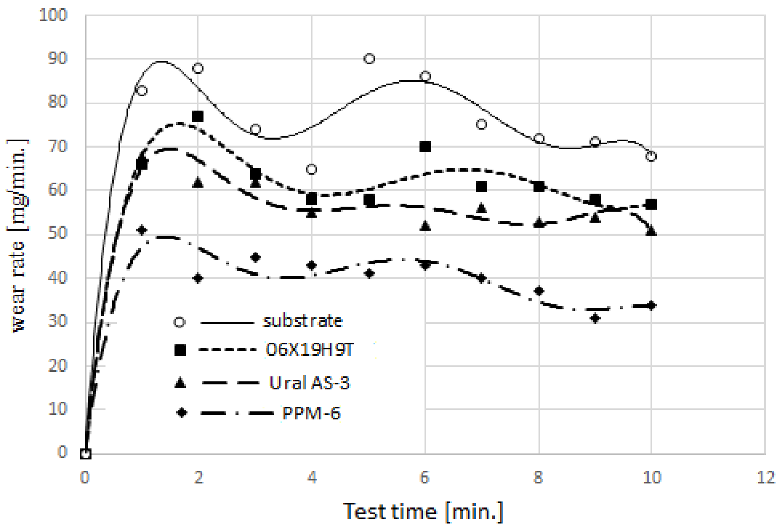

Figure 4. Results of three-body abrasion test of all studied materials (wear rate).

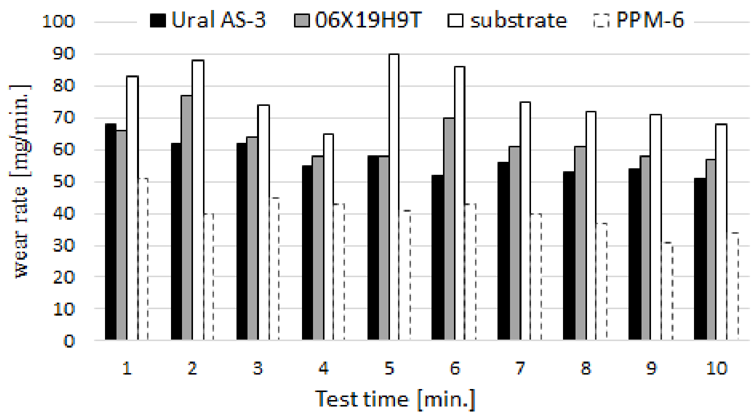

Figure 5. Wear rates during the three-body abrasion test for the tested materials.

The HV_{10} was measured for the deposited materials before and after the abrasive test. The results are labeled in Table 3. It is expected that the hardness after the abrasive test is somewhat higher than of that before testing due to work hardening in the affected area. However, this is not observed for the Ural AS-3 maybe due to presence of defects on the tested area. Nevertheless, it exhibited greater resistance to abrasive wear comparing with the 06X19H9T.

Table 4. The HV_{10} of the deposited materials.

Tested material	HV_{10} before testing	HV_{10} after testing
Ural AS-3	256 ± 2	244 ± 8
06X19H9T	242 ± 12	331 ± 26
PPM-6	685 ± 57	764 ± 5

3.2 Cavitation curves. The ultrasonic vibratory tests were conducted for all the studied materials by applying a combination of mechanical-electrochemical interaction, and the results are shown in Fig. 6. The cumulative mass loss-time curve was attained to evaluate the resistance of tested materials to cavitation erosion-corrosion. It can be easily distinguished the difference in mass loss between the substrate AISI 1040 steel and the deposited materials. Further, no significant difference can be noticed between the PPM-6 and the 06X19H9T steels. However, the best cavitation results are shown by the PPM-6 which exhibited higher resistance to cavitation followed by 06X19H9T, Ural AS-3 and substrate AISI 1040, respectively. In addition, the behavior of the studied materials during the cavitation test can be illustrated by the erosion rates calculated depending on the material loss at each interval of time, as shown in Fig. 7. Moreover, the maximum and minimum erosion rates attained during the cavitation tests for each tested material can be represented by bars graph shown in Fig. 8. It can be seen that the PPM-6 has the minimum erosion rate, in contrast, the substrate has the maximum erosion rate among all the tested materials. The minimum erosion rate achieved for the PPM-6 steel is 0.012 mg/min, while the maximum one is 0.434 mg/min for the AISI 1040 substrate steel. Moreover, the maximum erosion rate for both 06X19H9T and PPM-6 steels are very close to each other as illustrated in Fig.7, and they occurred at the last of the cavitation test.

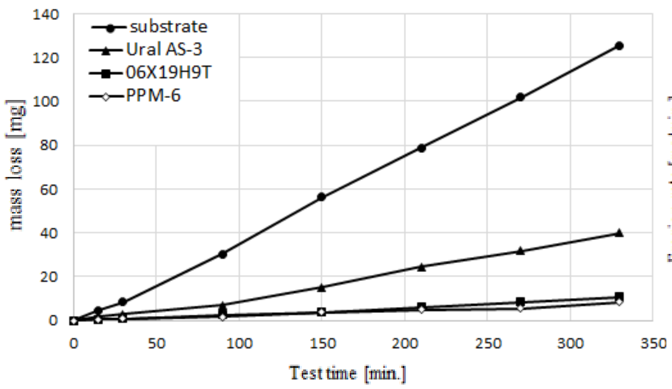

Figure 6. Cavitation results (mass loss) of all the studied materials.

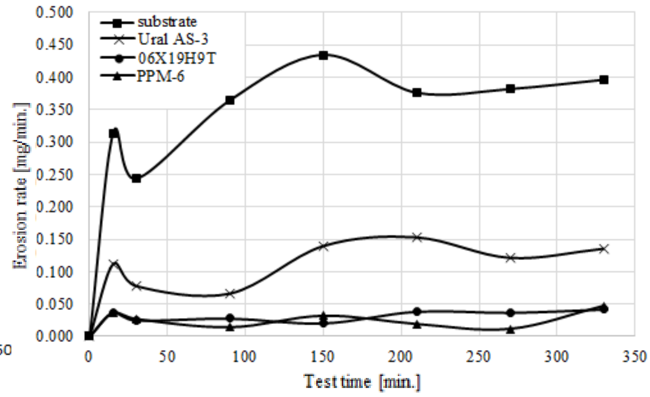

Figure 7. Behavior of the studied materials during the test (erosion rate).

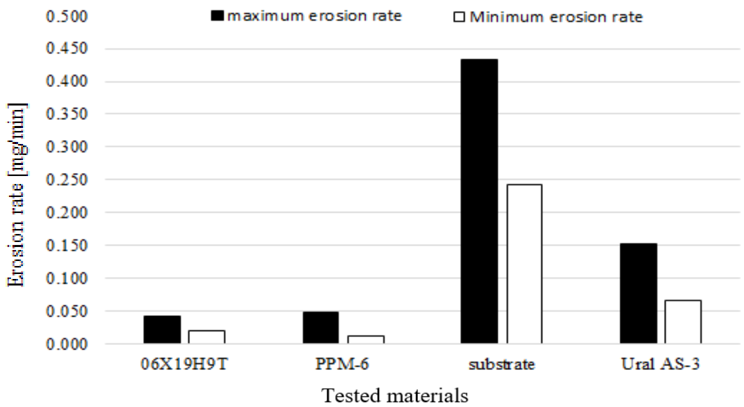

Figure 8. Maximum and minimum erosion rates of the studied materials during the cavitation test.

4. Conclusions

A three-body abrasion and an ultrasonic vibratory tests were performed to evaluate the resistance to abrasive wear and cavitation erosion-corrosion of deposited layers prepared from steels 06X19H9T and Fe-Cr-Ti-Al. The results showed the following:

- All the deposited materials exhibited a higher resistance to abrasive wear and cavitation than the substrate material AISI 1040 steel.
- Among all the tested materials, the PPM-6 showed the better resistance to the abrasive wear and cavitation erosion-corrosion.
- The cavitation results showed that both PPM-6 and 06X19H9T are almost identical.
- The 06X19H9T was exhibited a better resistance to cavitation comparing with the Ural AS-3. In contrast Ural AS-3 showed to some degree a better resistance than the 06X19H9T regarding the abrasive wear.
- For abrasive wear test, the PPM-6 has a better resistance than the substrate AISI 1040 steel, 06X19H9T, and Ural AS-3 by 90%, 56% and 41%, respectively. As for cavitation erosion-corrosion, the PPM-6 was exhibited a better resistance than the 06X19H9T by 30%, 5 times higher than Ural AS-3, and 15 times as high comparing with the AISI 1040 substrate steel.

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